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DESIGN ASSURANCE TEST OF A TE-M-479 APOGEE KICK MOTOR FOR THE RADIO ASTRONOMY EXPLORER SPACECRAFT

H. L. Merryman and R. M. Brooksbank

ARO, Inc.

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ENGINE TEST FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The test program reported herein was conducted at the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under the sponsorship of the National Aeronautics and Space Administration (NASA), Goddard Space Flight Center (GSFC), for the Thiokol Chemical Corporation (TTC), Elkton Division, under Program Element 921E, Project 9033.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in Propulsion Development Test Cell (T-3) of the Engine Test Facility (ETF) on May 2, 1973, under ARO Project Number RA293, and the manuscript was submitted for publication on August 8, 1973.

This technical report has been reviewed and is approved.

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ABSTRACT

One Thiokol Chemical Corporation TE-M-479 solid-propellant rocket motor, (S/N PV32-284-3) modified for use in the Radio Astronomy Explorer -B (RAE-B) spacecraft, was tested at an average pressure altitude of 110,000 ft while spinning about its axial centerline at 50 rpm. The primary objectives of this program were to determine the altitude ballistic performance of the motor when preconditioned at 40 ± 5°F, determine motor temperature-time history, evaluate component structural integrity, and determine the nonaxial (lateral) force produced by the motor while spinning about its axial centerline at 50 rpm. This test was conducted as a part of the design assurance program for the modified TE-M-479 motor. Motor ballistic performance, temperature-time history during and after motor operation, structural integrity evaluation, and lateral force data are presented and discussed.

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I. ILLUSTRATIONS

NOMENCLATURE

P_{max} Maximum chamber pressure, the highest chamber pressure developed during normal operation, excluding ignition transients, psia

t_a Action time, time interval between 10 percent of maximum chamber pressure during ignition and 10 percent of maximum chamber pressure during tailoff, sec

t_ℓ Ignition lag time, interval from zero time to time of increase in chamber pressure, sec

t_o Zero time, time at which firing voltage is applied to the ignition circuit, sec

t_{fb} Full duration burn time, time interval from first increase in thrust at ignition until thrust returns to the prefire level at tailoff, sec

SECTION I
INTRODUCTION

The Thiokol Chemical Corporation (TCC) TE-M-479 solid-propellant rocket motor is to be used as the Lunar Insertion Motor for the Radio Astronomy Explorer-B (RAE-B) spacecraft (Fig. 1, Appendix I). The scientific objective of the RAE-B mission is to obtain measurements of galactic and solar radio noise at frequencies below ionospheric cut-offs and external to terrestrial background interference by utilization of the moon for occulation, focusing, or aperture blocking for improved resolution and discrimination. The RAE-B will be placed in a lunar transfer trajectory by a Delta Vehicle, consisting of an Extended Long Tank Thor first stage (with MB-3 engine), augmented by nine Castor II solid strap-ons, an 8-ft-diam Transtage second stage, and a solid-propellant TE-364-3 third-stage rocket motor (Ref. 1).

The RAE-B Project will place a spacecraft into a circular lunar orbit of 3.6 x 10^6 ft (1100 km) altitude and 50 to 60-deg inclination to measure the direction and intensity of radio signals from celestial sources as a function of frequency, direction, and time. The RAE-B spacecraft will provide mapping of the galaxy without the perturbing effects of the terrestrial ionosphere. Selected frequencies from 0.03 to 20 mHz will be investigated (Ref. 1).

The spacecraft antennas will consist of two V antennas formed by deploying four booms, 0.5 in. in diameter and 750 ft in length. A third antenna will consist of a dipole deployed normal to the Z (longitudinal) axis of the spacecraft (Ref. 1).

The motor reported herein differed from the two reported in Ref. 2 in that the aft pressure relief boot had been modified (see Section 2.1).

The primary objectives of the test reported herein were to determine the altitude ballistic performance of the TE-M-479 rocket motor when spinning at 50 rpm after prefire temperature conditioning at 40 ± 5°F, determine motor temperature-time history, evaluate component structural integrity of the modified TE-M-479 rocket motor, and determine the nonaxial (lateral) force produced by the motor. A secondary objective was to determine the effect of the modified relief boot on motor ballistic performance and structural integrity (Ref. 3).

Motor altitude ballistic performance, temperature history data, structural integrity, and motor nonaxial thrust are discussed.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The Thiokol Chemical Corporation (TCC) TE-M-479 solid-propellant rocket motor (Fig. 1) is a full-scale, flightweight motor having the following nominal dimensions and burning characteristics at 40°F:

Length, in.	27
Diameter, in.	17.5
Loaded Weight, lbm	175
Propellant Weight, lbm	153
Maximum Thrust, lbf	2500
Maximum Chamber Pressure, psia	830
Burn Time, sec	21
Throat Area, in.^{2}	1.48
Nozzle Area Ratio, A/A*	60

The cylindrical motor case is constructed of 0.040-in. titanium. The case is lined internally with TCC TL-H-304 liner and insulated with asbestos-filled Buna-N rubber. A pressure relief boot assembly is contained in the forward and aft end of the motor case (Fig. 1). A flange located on the aft dome provides for attachment to the RAE-B spacecraft.

Previous TE-M-479 motors (Ref. 2) utilized a pressure relief boot extending from the igniter port circumferentially around the perimeter of the grain to a position about 2-in. aft of the case midpoint (Fig. 1). Investigation by the motor manufacturer indicated a possibility that during ignition a part of the relief boot aft of the aft grain surface could seal against the primary insulator and cause a propellant-to-boot bond failure. For the motor reported herein, the relief boot was trimmed back to within 0.3 in. of the aft propellant surface (Fig. 1b).

The contoured nozzle assembly contains a Graph-I-Tite® G-90 carbon throat insert and an expansion cone constructed of vitreous silica phenolic. The nozzle assembly has a nominal 60:1 area ratio and a 15-deg half-angle at the exit plane. A Styrofoam® closure was bonded in the nozzle expansion cone. The closure was punctured prior to the test so that the rocket motor chamber pressure was equal to test cell pressure at motor ignition.

The TE-M-479 rocket motor contains a propellant grain formulation designated TP-H-3062 (ICC Class B), cast in an eight-point star configuration.

Ignition was accomplished by a TE-P-386-7 pyrogen igniter (Fig. 1a) which contained 20, size 2A, $BKNO_3$ pellets used to initiate the primary polysulfide igniter grain. Nominal ignition current was 4 amp and was maintained for approximately 0.3 sec. The motor contained two pyrogen igniters: however, only one igniter was used in this test.

2.2 INSTALLATION

The motor assembly was cantilever mounted from the spindle face of a spin fixture assembly in Propulsion Development Test Cell (T-3). The spin assembly was mounted on a thrust cradle, which was supported from the cradle support stand by three vertical and two horizontal double-flexure columns (Fig. 2). The spin fixture assembly consists of a 10-hp squirrel-cage-type drive motor, a forward thrust bearing assembly, a 46-in.-long spindle having a 36-in.-diam aft spindle face, and an aft bearing assembly. The

spin fixture was rotated counterclockwise, looking upstream. Electrical leads to and from the igniters, pressure transducers, strain grid, and thermocouples on the rotating motor were provided through a 170-channel, slip-ring assembly mounted between the forward and aft bearing assemblies on the spindle. Axial thrust was transmitted through the spindle-thrust bearing assembly to two load cells mounted just forward of the thrust bearing.

Pre-ignition pressure altitude conditions were maintained in the test cell by a steam ejector operating in series with the ETF exhaust gas compressors. During a motor firing, the motor exhaust gases were used as the driving gas for the 29-in.-diam, ejector-diffuser system to maintain test cell pressure at an acceptable level.

2.3 INSTRUMENTATION

Instrumentation was provided to measure axial thrust, motor chamber pressure, test cell pressure, lateral force, motor case and nozzle temperatures, motor case strain, rotational speed, and rocket exhaust radiation. Table I (Appendix II) presents instrument ranges, recording methods, and system accuracies for the reported parameters.

The axial thrust measuring system consisted of two double-bridge, strain-gage-type load cells mounted in the axial double-flexure column forward of the thrust bearing on the spacecraft centerline. The lateral force measuring system consisted of double-bridge, strain-gage-type load cells installed forward and aft between the flexure-mounted cradle and the cradle support stand normal to the rocket motor axial centerline and in the horizontal plane passing through the motor axial centerline (Fig. 2c).

Unbonded strain-gage-type transducers were used to measure test cell pressure. Bonded strain-gage-type transducers with ranges of 0 to 50 and 0 to 1000 psi were used to measure motor chamber pressures. Chromel®-Alumel® (CA) thermocouples were bonded to the motor case and nozzle (Fig. 3) to measure outer surface temperatures during and after motor burn time. Rotational speed of the motor-spacecraft assembly was determined from the output of a magnetic pickup.

Five radiometers and one calorimeter, furnished by the sponsor, were used to measure the heat flux from the rocket exhaust. Calibration factors for data reduction were supplied by the manufacturer. The units were oriented as shown in Fig. 3b.

The output signal of each measuring device was recorded on independent instrumentation channels. Primary data were obtained from four axial thrust channels, three test cell pressure channels, and three motor chamber pressure channels. These primary data were recorded as follows: Each instrument output signal was indicated in totalized digital form on a visual readout of a millivolt-to-frequency converter. A magnetic tape system, recording in frequency form, stored the signal from the converter for reduction at a later time by an electronic digital computer. The computer provided a tabulation of average absolute values for each 0.10-sec time increment and total integrals over the cumulative time increments.

The output signal from the magnetic rotational speed pickup was recorded in the following manner: A frequency-to-analog converter was triggered by the pulse output from the magnetic pickup and in turn supplied a square wave of constant amplitude to the electronic counter and oscillograph recorder. The scan sequence of the electronic counter was adjusted so that it displayed directly the motor spin rate in revolutions per minute.

The millivolt outputs of the lateral (nonaxial) force load cells, radiometers, strain grid, and thermocouples were recorded on magnetic tape from a multi-input, analog-to-digital converter and reduced to engineering units by an electronic computer.

A recording oscillograph was used to provide an independent backup of all operating instrumentation channels except the temperature systems. Selected channels of thrust and pressures were recorded on null-balance, potentiometer-type strip charts for analysis immediately after a motor firing. Visual observation of each firing was provided by a closed-circuit television monitor. High-speed, motion-picture cameras provided a permanent visual record of each firing.

2.4 CALIBRATION

The thrust calibrator weights, axial and lateral force load cells, and pressure transducers were laboratory calibrated prior to usage in this program. After installation of the measuring devices in the test cell, all systems were calibrated at ambient conditions and again at simulated altitude conditions (with the motor spinning) just before a motor firing.

The pressure systems were calibrated by an electrical, four-step calibration, using resistances in the transducer circuits to simulate selected pressure levels. The axial thrust instrumentation systems were calibrated by applying to the thrust cradle known forces which were produced by deadweights acting through a bell crank. The calibrator is hydraulically actuated and remotely operated from the control room. The side force instrumentation systems were calibrated by an electrical, four-step calibration, using resistances in the circuits to simulate selected force levels. Thermocouple systems were calibrated by using known millivolt levels to simulate selected thermocouple outputs.

After each motor firing, with the test cell still at simulated altitude pressure, the systems were again recalibrated to determine if any shift had occurred.

SECTION III
PROCEDURE

The TCC TE-M-479 rocket motor (S/N PV32-284-3) arrived at AEDC on April 10, 1973. The motor was visually inspected for possible shipping damage and radiographically inspected for grain cracks, voids, or separations and found to meet criteria provided by the manufacturer. During storage in an area temperature conditioned at 70 ± 5°F, the motor was checked to ensure correct fit of mating hardware, and the electrical resistances of the igniters were measured. Thermocouples were bonded to the nozzle and motor case, and the entire motor assembly was weighed and photographed. Prefire nozzle throat measurements were not taken because of the presence of the nozzle closure.

The built-up motor assembly was installed on a spin table and radial dimensions of selected surfaces as a function of angular position relative to the spin axis of the rocket motor were then determined to facilitate alignment of the motor-spacecraft assembly in the test cell. The motor was leak checked by Thiokol personnel prior to installation.

After installation of the motor assembly in the test cell, the centerline was axially aligned with the spin axis by rotating the motor assembly and measuring the deflection of the nozzle lip and adapter flange surfaces with a dial indicator and making appropriate adjustments. Instrumentation connections were made, and the motor assembly was balanced at a rotational speed of 50 rpm. Temperature conditioning of the motor-spacecraft assembly (40°F) was begun and continued for a period in excess of 24 hr. The two pyrogen igniters were installed, the motor was leak checked, and a continuity check of all electrical systems was performed. Prefire ambient calibrations were completed, the test cell pressure was reduced to simulate the desired altitude, and spinning of the unit was started. After spinning had stabilized at 50 rpm, a complete set of altitude calibrations was taken.

The final operation prior to firing the motor was to adjust the firing circuit resistance to provide the desired current (4 amp) to the igniter squib (the motor contained two igniters; however, only one was used to ignite the motor). The entire instrumentation measuring-recording complex was activated, and the motor was fired while spinning (under power) at 50 rpm.

Spinning of the motor was continued for approximately 45 min after burnout, during which time motor temperatures were recorded and postfire calibrations were accomplished. The unit was decelerated slowly until rotation had stopped, and another set of calibrations was taken. The test cell pressure was then returned to ambient conditions, and the motor assembly was inspected, photographed, and removed to the storage area. Postfire inspection at the storage area consisted of measuring the throat and exit diameters of the nozzle, weighing the motor, and photographically recording the postfire condition of the motor.

SECTION IV
RESULTS AND DISCUSSION

One Thiokol Chemical Corporation TE-M-479 solid-propellant rocket motors (S/N PV32-284-3) was fired in Propulsion Development Test Cell (T-3). The motor was prefire temperature conditioned at 40 ± 5°F for a period in excess of 24 hr and fired at an average pressure altitude in excess of 110,000 ft with the motor assembly spinning about the spacecraft longitudinal axis at 50 rpm. The primary objectives of the test program were to determine motor altitude ballistic performance at 40°F, evaluate motor structural integrity, determine motor temperature-time history during and after motor operation, and measure the lateral (nonaxial) thrust component. A secondary objective was to determine the effect of the modified relief boot on motor ballistic performance and structural integrity. The resulting data are presented in both tabular and graphical form. Motor performance data based on action time (t_a) and full-duration burn time (t_{fb}) are summarized in Table II. The average measured total impulse values were corrected to vacuum by adding the product of the cell pressure integral and the average of the pre- and postfire nozzle exit areas. Specific impulse values are presented using both the

manufacturer's stated propellant weight and the motor expended mass determined from AEDC pre- and postfire motor weights. When multiple channels of equal accuracy instrumentation were used to obtain values of a single parameter, the average value was used to calculate the data presented.

4.1 ALTITUDE IGNITION CHARACTERISTICS

The motor was ignited at a pressure altitude of 119,000 ft with the pre-punctured nozzle closure bonded in place. The variations of thrust and chamber pressure during motor ignition are presented in Fig. 4. The ignition lag time (t_ℓ) was 0.013 sec. The ignition lag times (t_ℓ) for the two previously tested motors (Ref. 2) were 0.010 sec for motor S/N 7 (40°F) and 0.011 sec for motor S/N 10 (90°F).

4.2 ALTITUDE BALLISTIC PERFORMANCE

Variations of thrust, chamber pressure, and cell pressure during the firing are shown in Fig. 5. The motor burning characteristics were as expected.

Vacuum total impulse based on action time (t_a) of 19.90 sec was 44,064 lbf-sec. Vacuum total impulse based on full-duration burn time (t_{fb}) of 21.70 sec was 44,225 lbf-sec. The predicted vacuum total impulse for this motor, when conditioned at 40°F, was 44,379 lbf-sec (Ref. 3) and agrees within 0.3 percent from that reported above.

Vacuum specific impulse for the motor reported herein, based on t_{fb} and the manufacturer's stated propellant weight, was 288.47 lbf-sec/lbm. Comparable specific impulses for the two motors reported in Ref. 2 were 289.97 lbf-sec/lbm (S/N 7, 40°F) and 290.63 lbf-sec/lbm (S/N 10, 90°F).

4.3 STRUCTURAL INTEGRITY

Postfire examination of the motor case and nozzle assembly did not reveal any evidence of thermal damage (Fig. 6). The pre- to postfire nozzle throat area increased 17.2 percent, and the nozzle exit area decreased about 1.5 percent (Table III). The throat area erosion was about 6 percent less than the erosion noted for the two motors reported in Ref. 2.

Motor case and nozzle temperature variations with time are presented in Fig. 7. The maximum motor case temperature was about 530°F (TC-5, Fig. 7c) and occurred about 310 sec after motor ignition.

The maximum motor case temperature in the region where the relief boot was removed (Fig. 1b) was about 460°F (TC-15, Fig. 7e) and occurred about 370 sec after motor ignition. Comparable temperature measurements were not made in this region for the tests reported in Ref. 2; however, comparable maximum temperature measurements adjacent to this region (TC-10, TC-11, TC-12, and TC-13) (400 to 475°F) were approximately the same magnitude as those reported in Ref. 2.

4.4 LATERAL (NONAXIAL) THRUST VECTOR MEASUREMENT

A test objective was to measure the lateral component of the axial thrust. The recorded lateral thrust data were corrected for installation and/or electronic effects as described in Ref. 4. The resultant data are presented in Fig. 8.

The maximum magnitude of lateral thrust recorded during the near steady-state portion of motor operation was about 2.2 lbf and occurred about 3 sec after motor ignition (Fig. 8). The average magnitude of lateral thrust measurement is about 1.7 lbf.

4.5 HEAT FLUX DATA

Five narrow-angle radiometers and one wide-angle calorimeter were used to obtain rocket exhaust plume radiation heat flux data. The instruments were positioned around the nozzle assembly as shown in Fig. 3b.

The variation of radiation heat flux with time is presented in Fig. 9. The maximum radiation was about 10.5 Btu-ft^2-sec during motor burning and occurred 16 sec after motor ignition. Measured radiation heat flux increased throughout the firing.

SECTION V
SUMMARY OF RESULTS

One Thiokol Chemical Corporation TE-M-479 solid-propellant rocket motor was successfully fired at an average pressure altitude of 110,000 ft while spinning about the motor axial centerline at 50 rpm following temperature conditioning at 40 ± 5°F for a minimum of 24 hr. The primary objectives of the test program were to determine motor altitude ballistic performance, evaluate motor structural integrity, determine motor temperature-time history during and after motor operation, and measure the lateral (nonaxial) thrust component. A secondary objective was to determine the effect of the modified relief boot on motor ballistic performance and structural integrity. The results are summarized as follows:

1. Ignition lag time, the time interval from application of firing voltage until the first increase in chamber pressure, was 0.013 sec.

2. Action time, the time interval from 10 percent of maximum chamber pressure during ignition and 10 percent of maximum chamber pressure during tailoff, was 19.90 sec.

3. Full-duration burn time, the time interval from the first increase in thrust during ignition to the time that thrust has decreased to zero during tailoff, was 21.70 sec.

4. Vacuum total impuse, based on full-duration burn time, was 44,225 lbf-sec, which agrees within 0.3 percent of the predicted impulse of 44,379 lbf-sec.

5. No thermal damage was noted on the motor case or nozzle assembly. The nozzle throat area increased about 17.2 percent during the firing.

6. The maximum motor case temperature was about 530°F and occurred about 310 sec after motor ignition. The maximum motor case temperature in the region where the relief boot was removed was 460°F and occurred approximately 370 sec after motor ignition.

7. The maximum magnitude of lateral thrust recorded during the near steady-state portion of motor operation was about 2.2 lbf. The average magnitude of lateral thrust was about 1.7 lbf.

8. The maximum radiation heat flux was about 10.5 Btu/ft^2-sec and occurred 16 sec after motor ignition. Measured radiation heat flux increased throughout the firing.

9. The modified aft pressure relief boot appeared to have no effect on motor ballistic performance or motor structural integrity.

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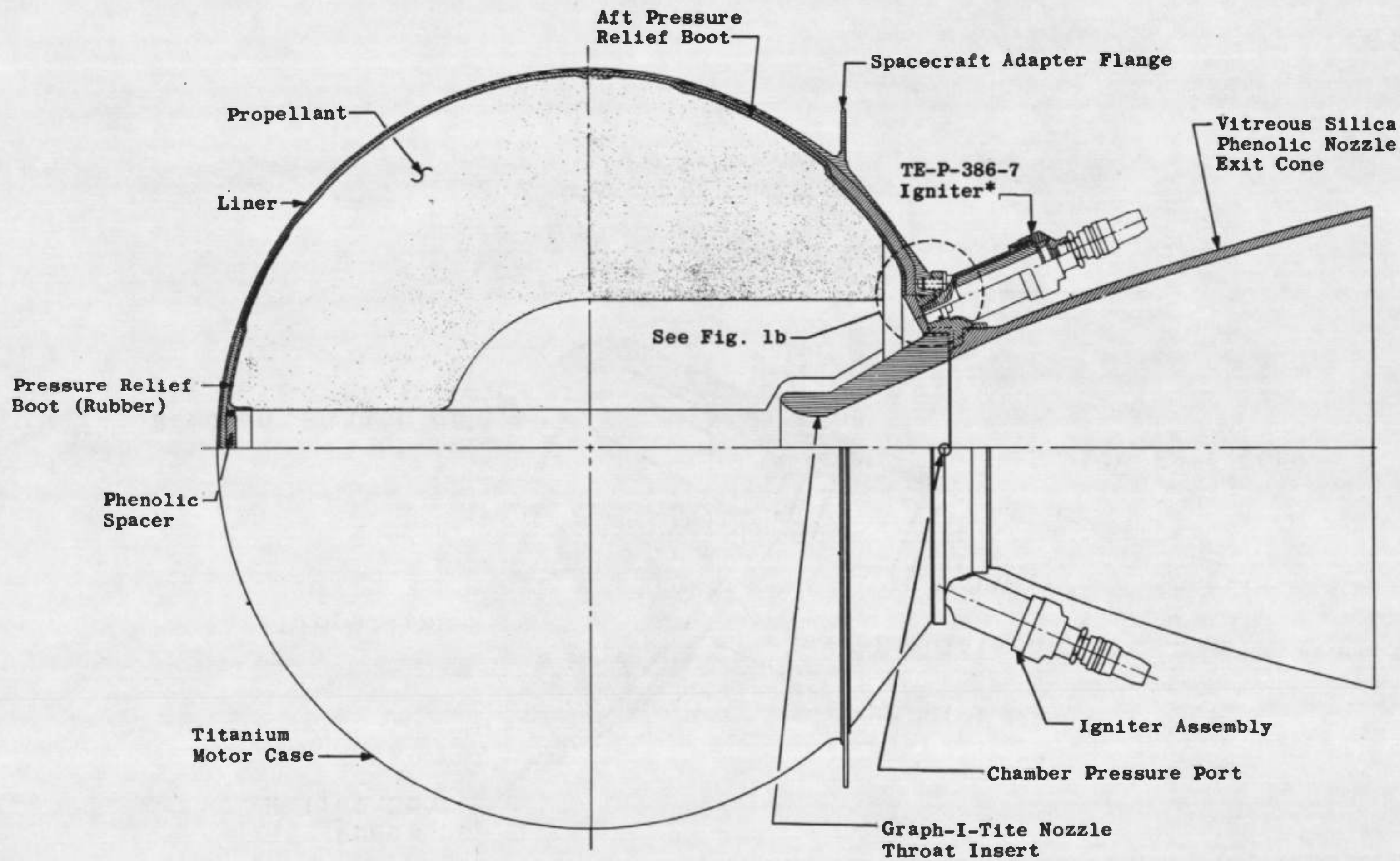
1. W. R. Schindler. "Background Information on TE-M-479 Rocket Motor." NASA, Goddard Spaceflight Center, File 15747, April 30, 1973.

2. White, D. W. and Harris, J. E. "Evaluation of Two Radio Astronomy Explorer Spacecraft Apogee Kick Motors Tested in the Spin Mode at Simulated Altitude Conditions." AEDC-TR-67-127 (AD817821), July 1967.

3. Test Plan 5202-190 Rev. 1, for RAE Kick Motor TE-M-479, Thiokol Chemical Corporation, Elkton, Maryland, April 5, 1973.

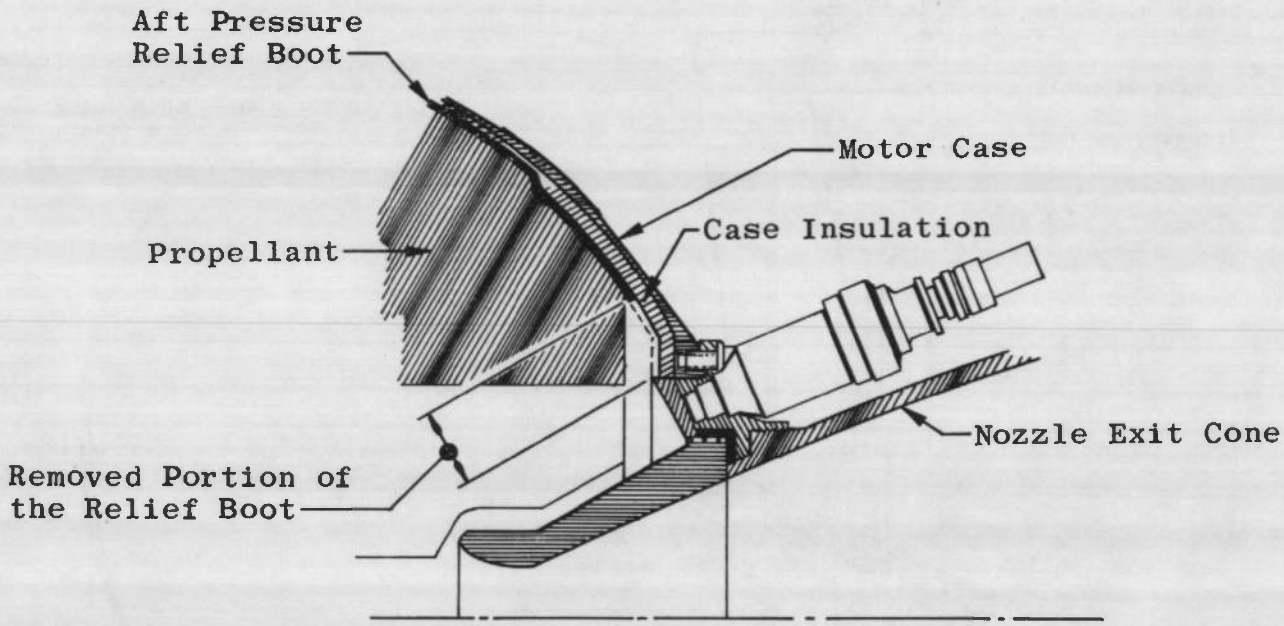
4. Nelius, M. A. and Harris, J. E. "Measurements of Nonaxial Forces Produced by Solid-Propellant Rocket Motors Using a Spin Technique." AEDC-TR-65-228 (AD474410), November 1965.

APPENDIXES
I. ILLUSTRATIONS
II. TABLES

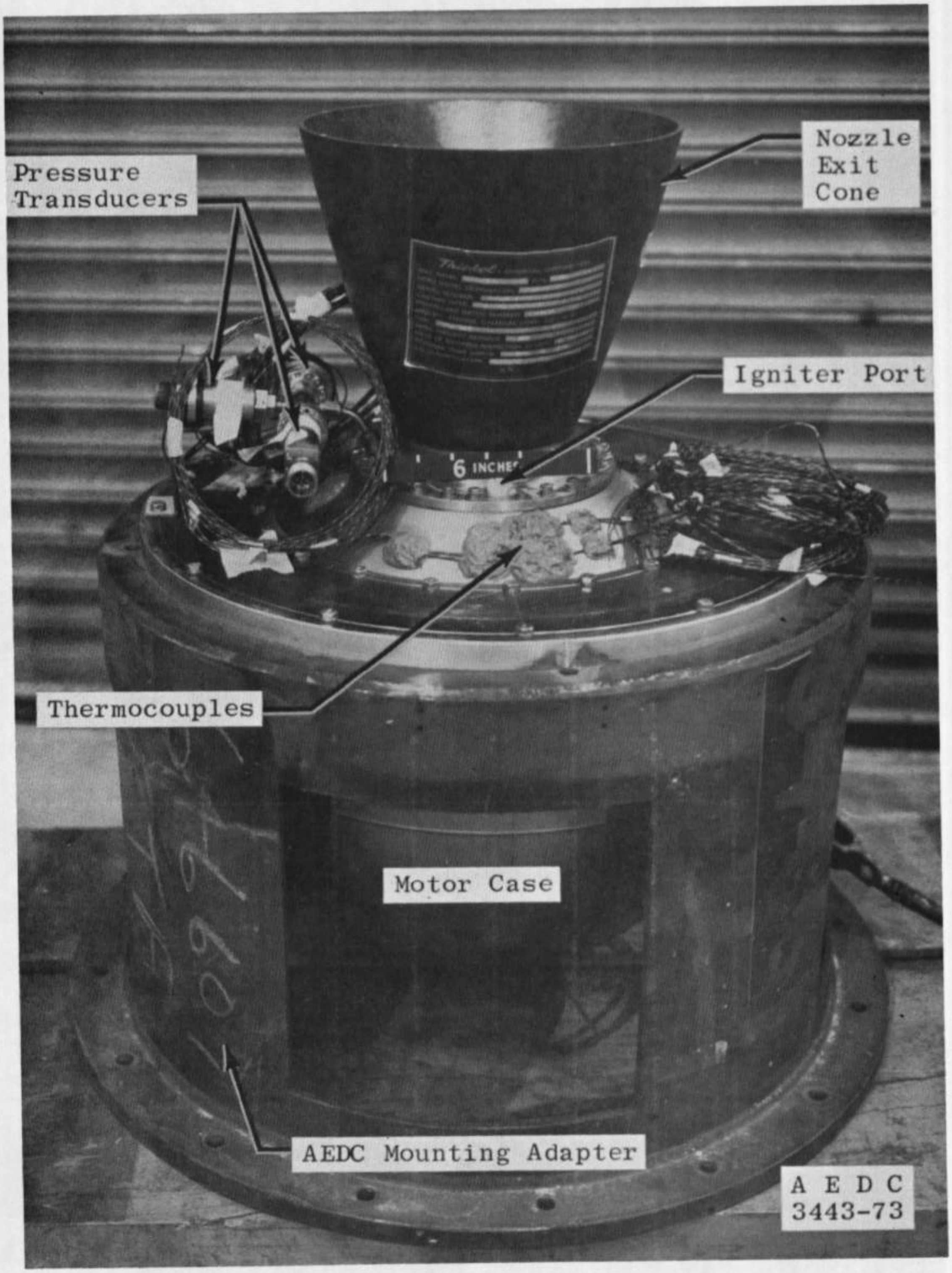


*Only one of the two igniters contained a squib.

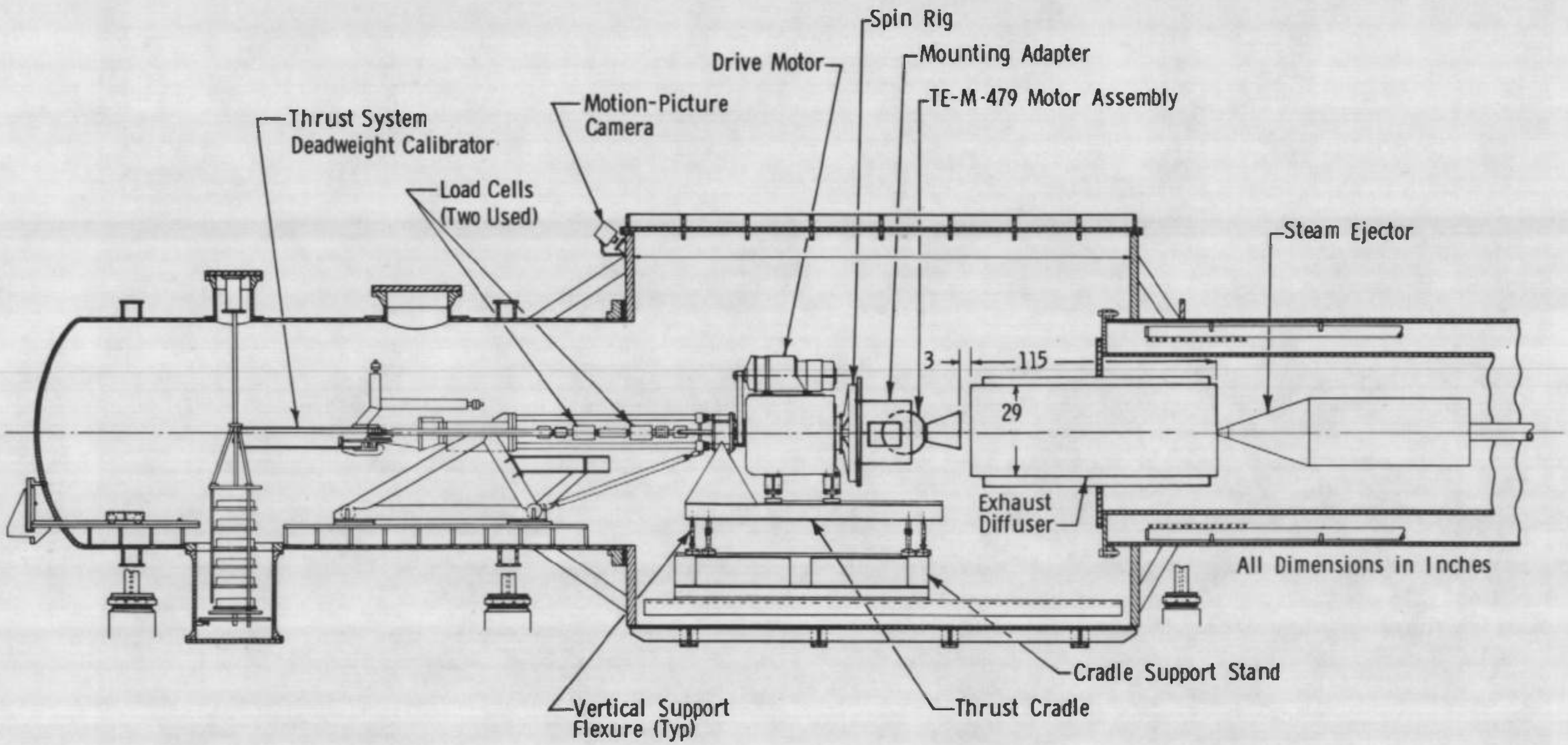
a. Motor Schematic
Fig. 1 TE-M-479 Rocket Motor



b. Schematic of Relief Boot Section
Fig. 1 Continued

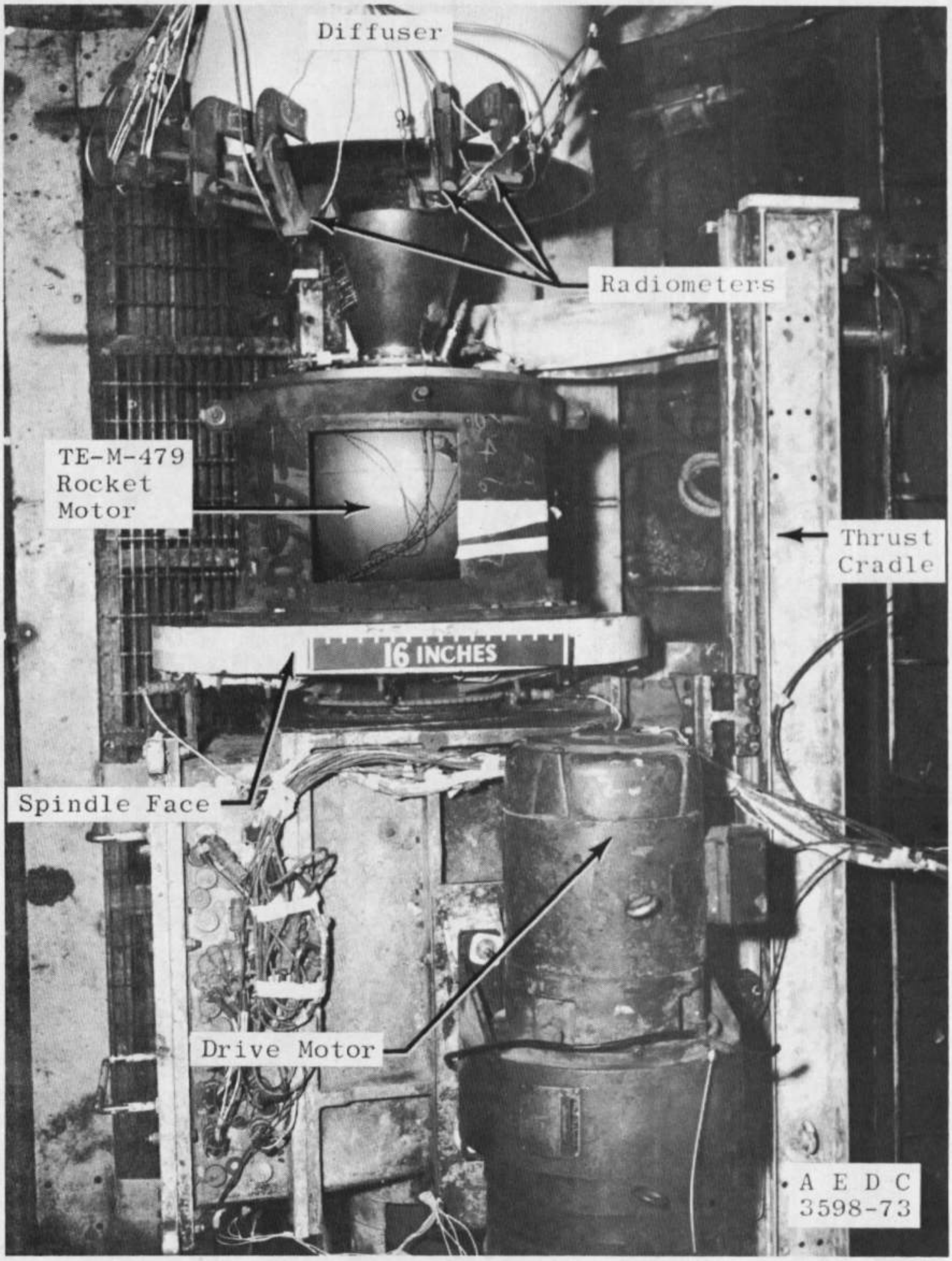


c. Motor Photograph
Fig. 1 Concluded

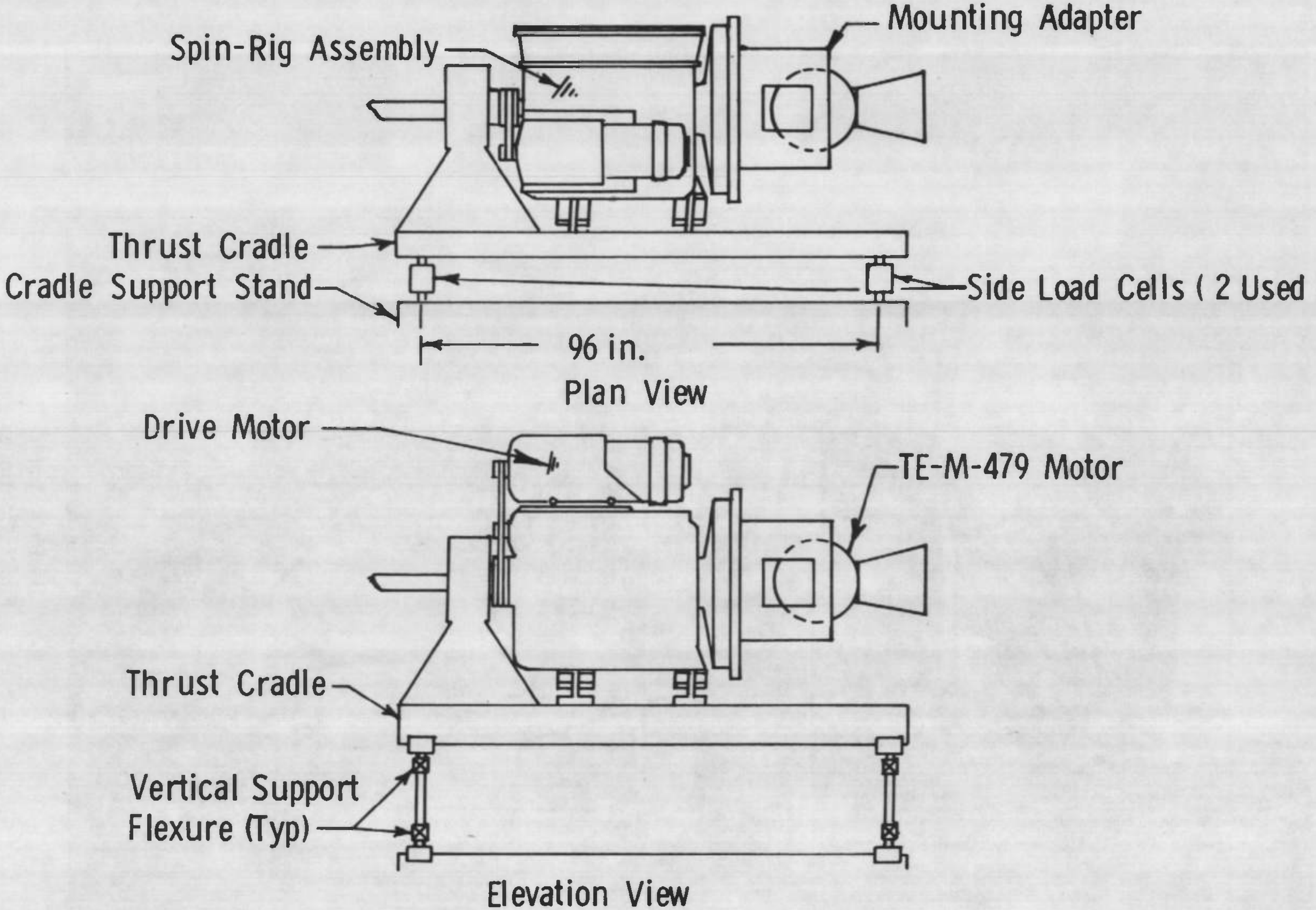


a. Schematic

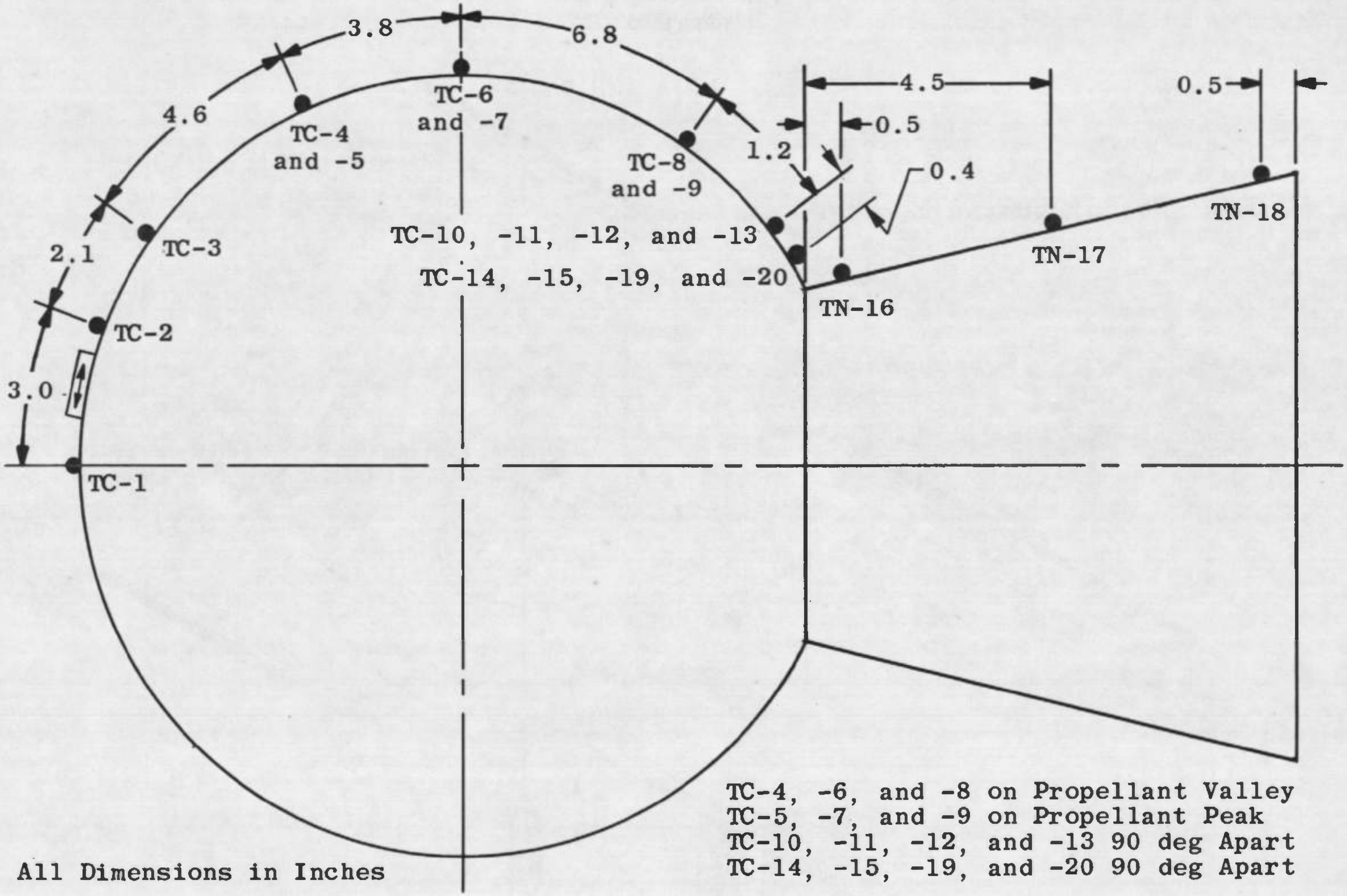
Fig. 2 Installation of the Thiokol TE-M-479 Rocket Motor in Propulsion Development Test Cell (T-3)



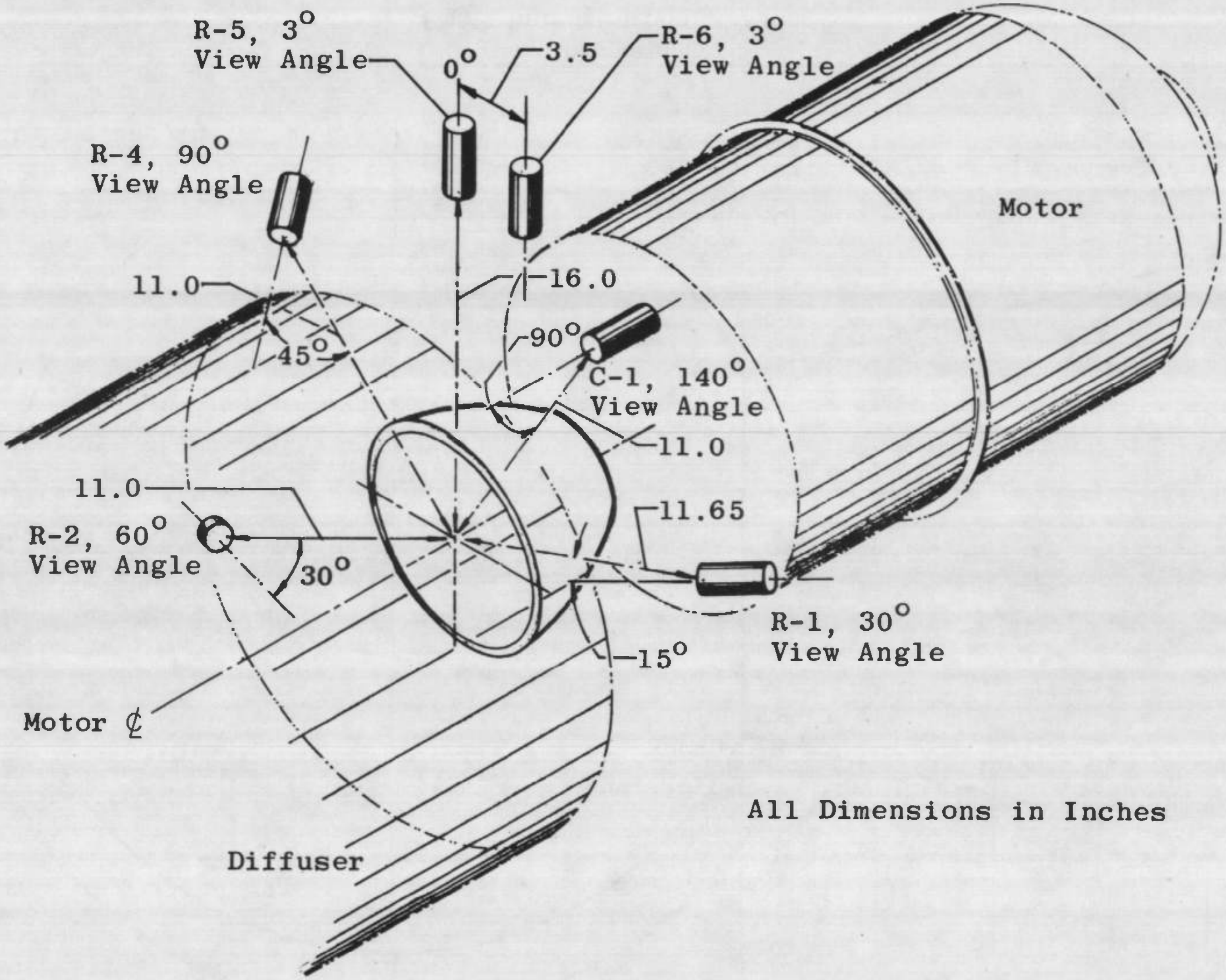
b. Photograph
Fig. 2 Continued



c. Detail
Fig. 2 Concluded



a. Thermocouples
Fig. 3 Instrumentation Locations



b. Radiometers
Fig. 3 Concluded

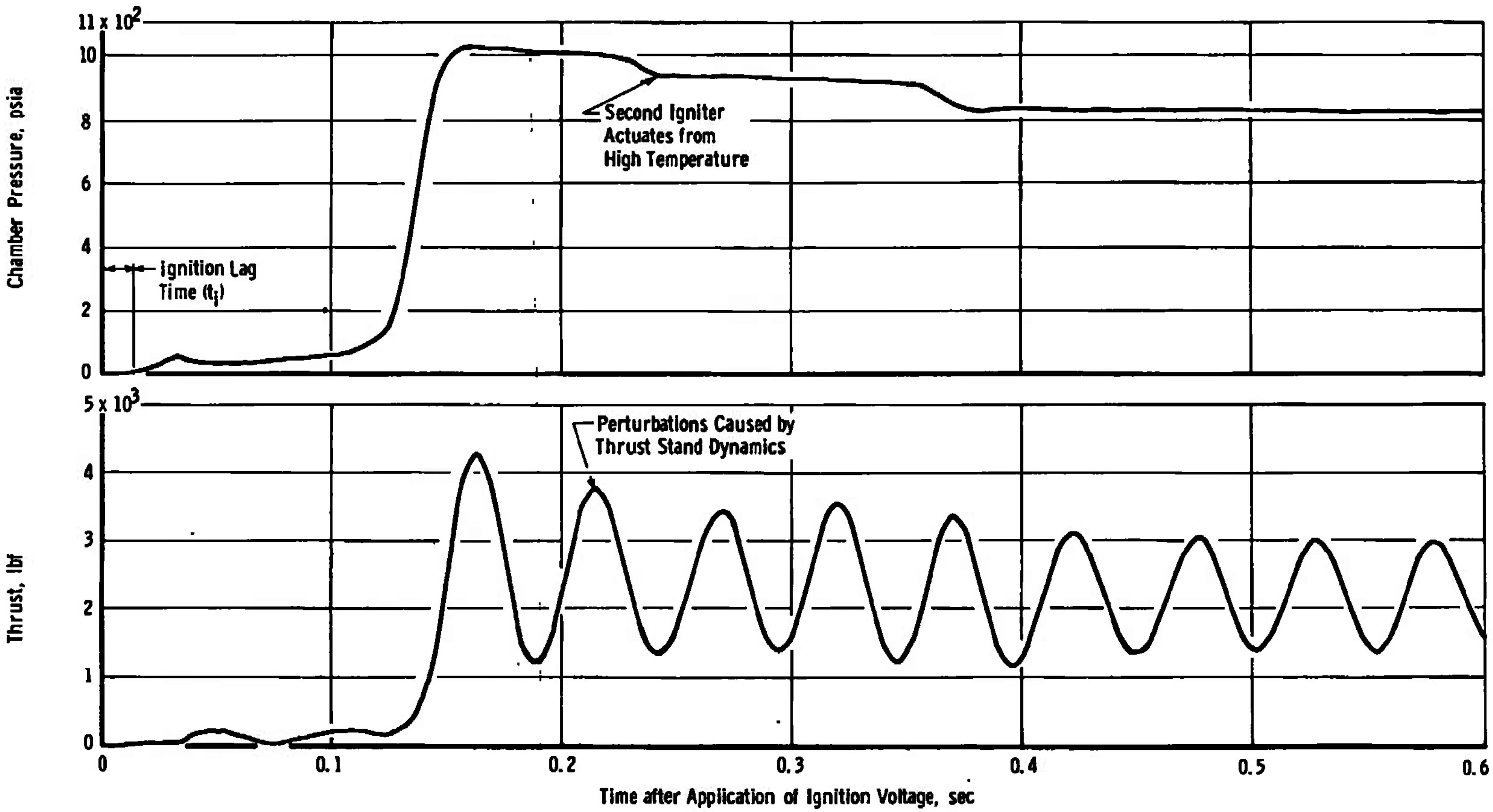


Fig. 4 Variation of Thrust and Chamber Pressure during the Ignition Event

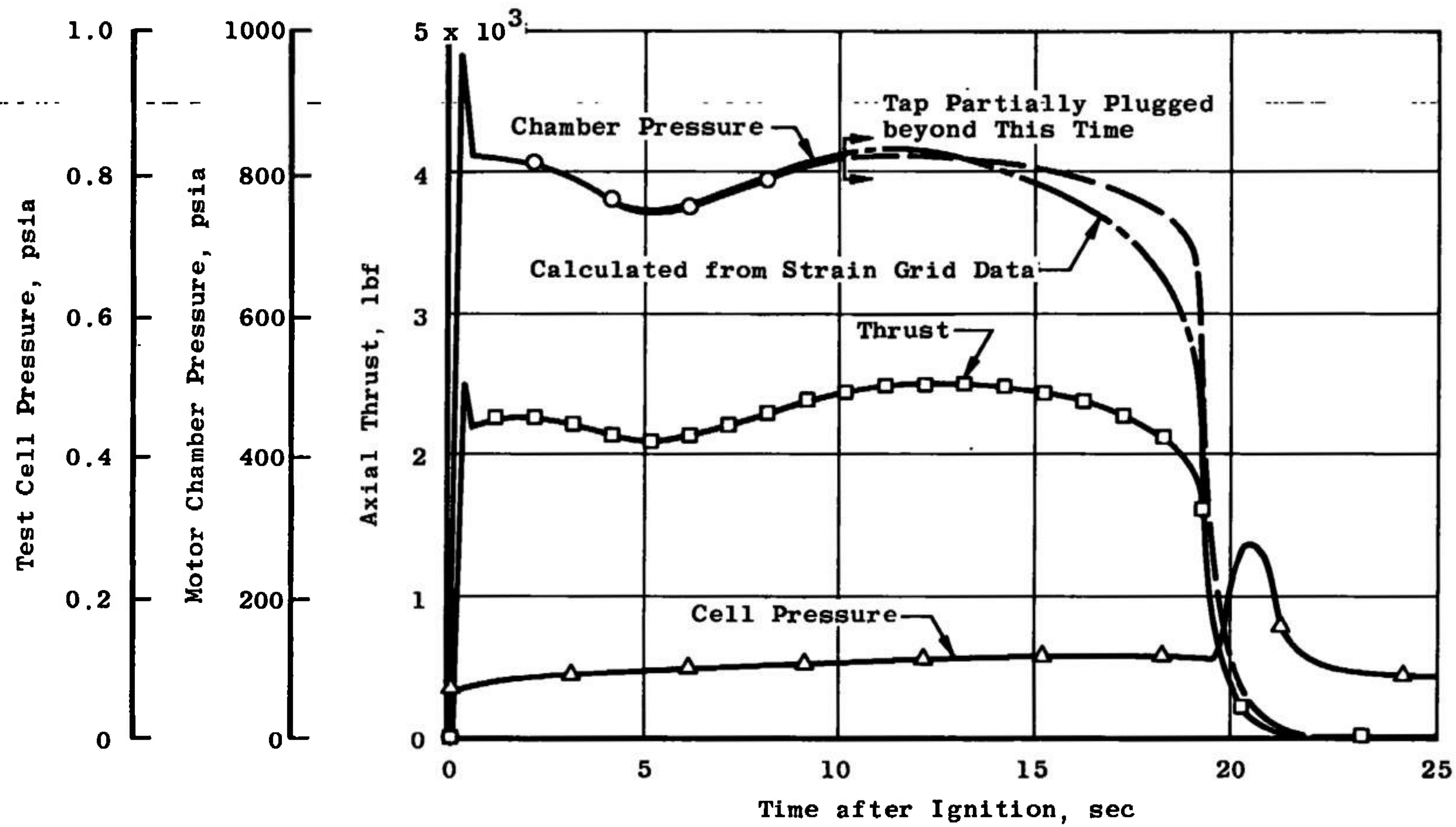
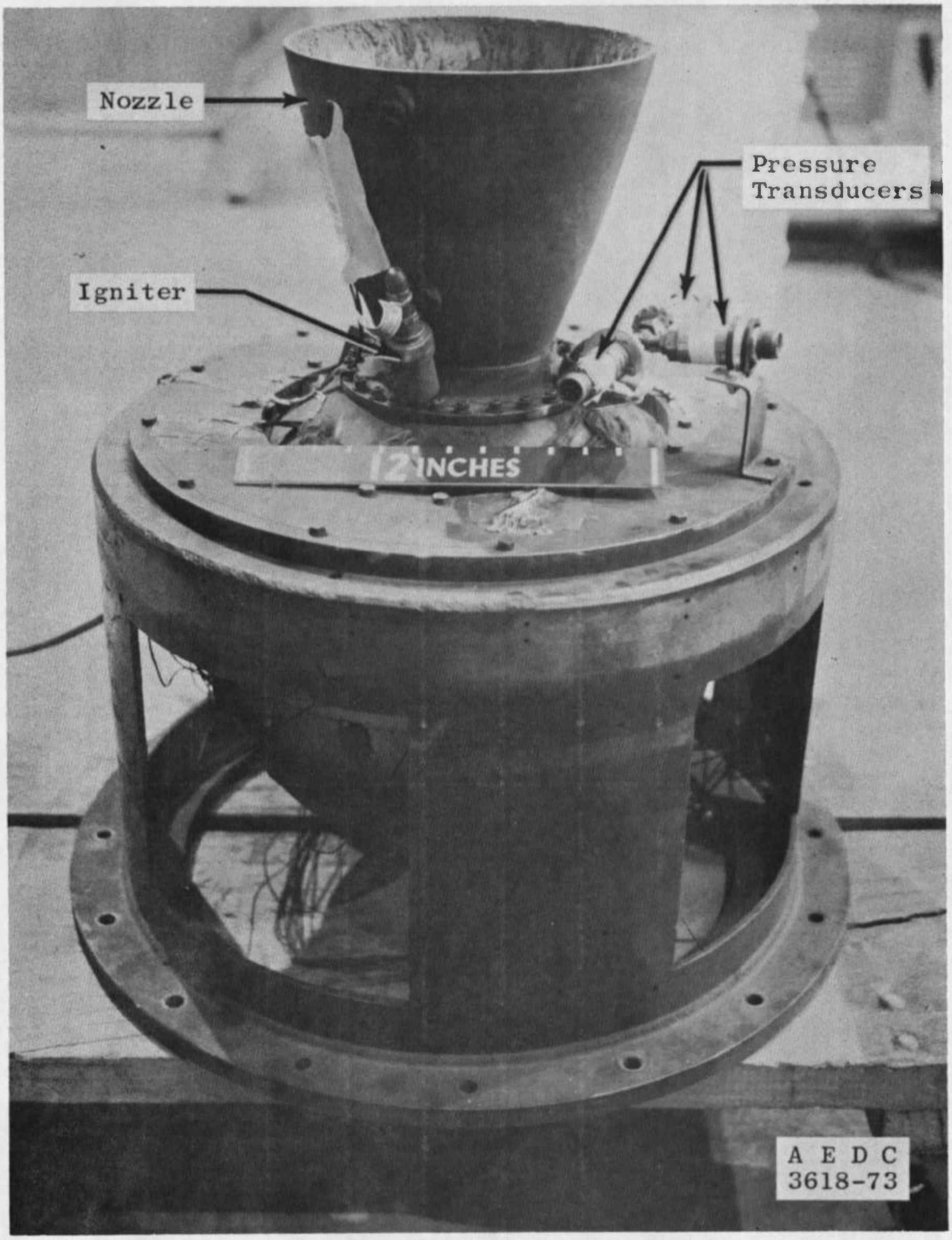
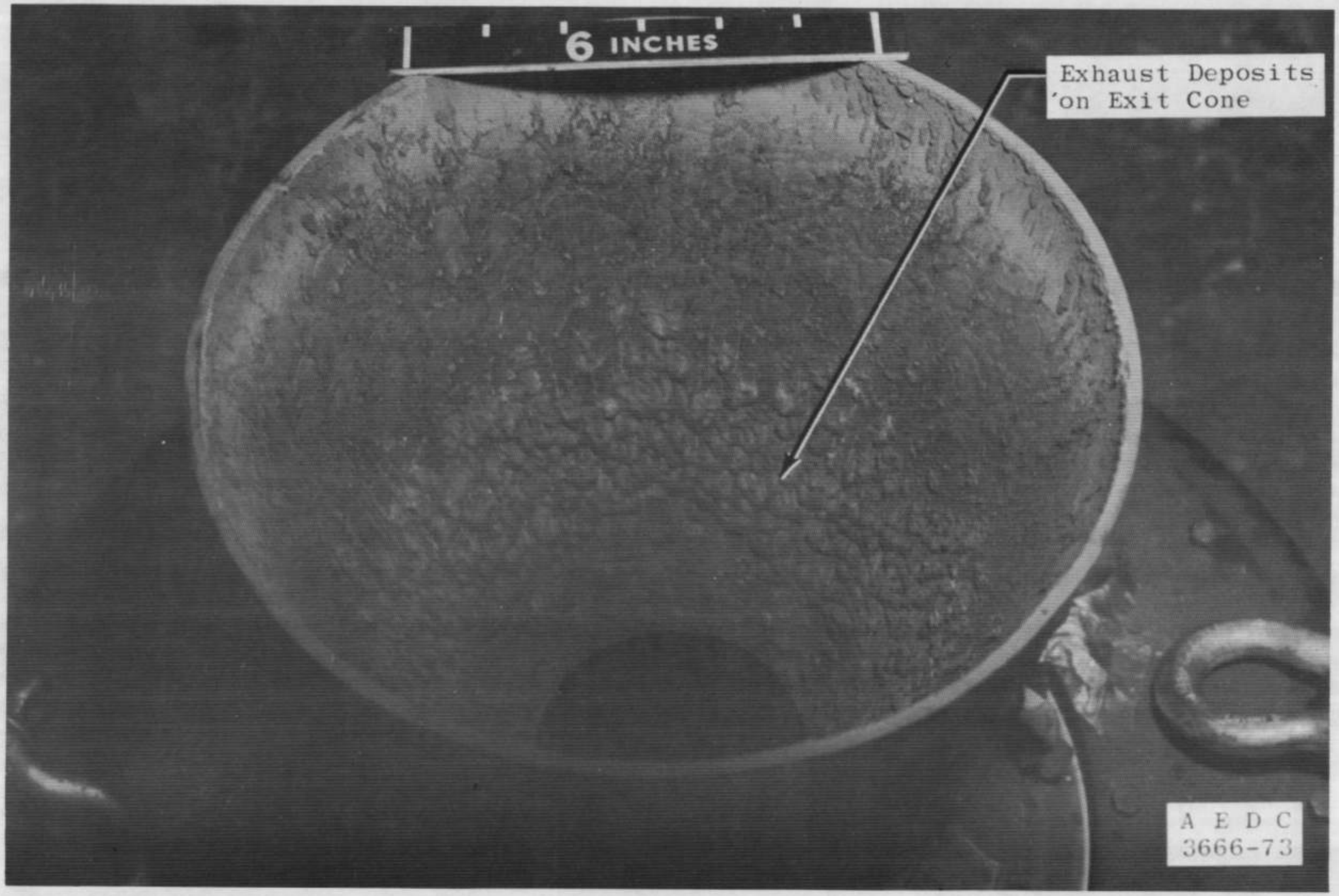


Fig. 5 Variation of Thrust, Chamber Pressure, and Test Cell Pressure during Firing

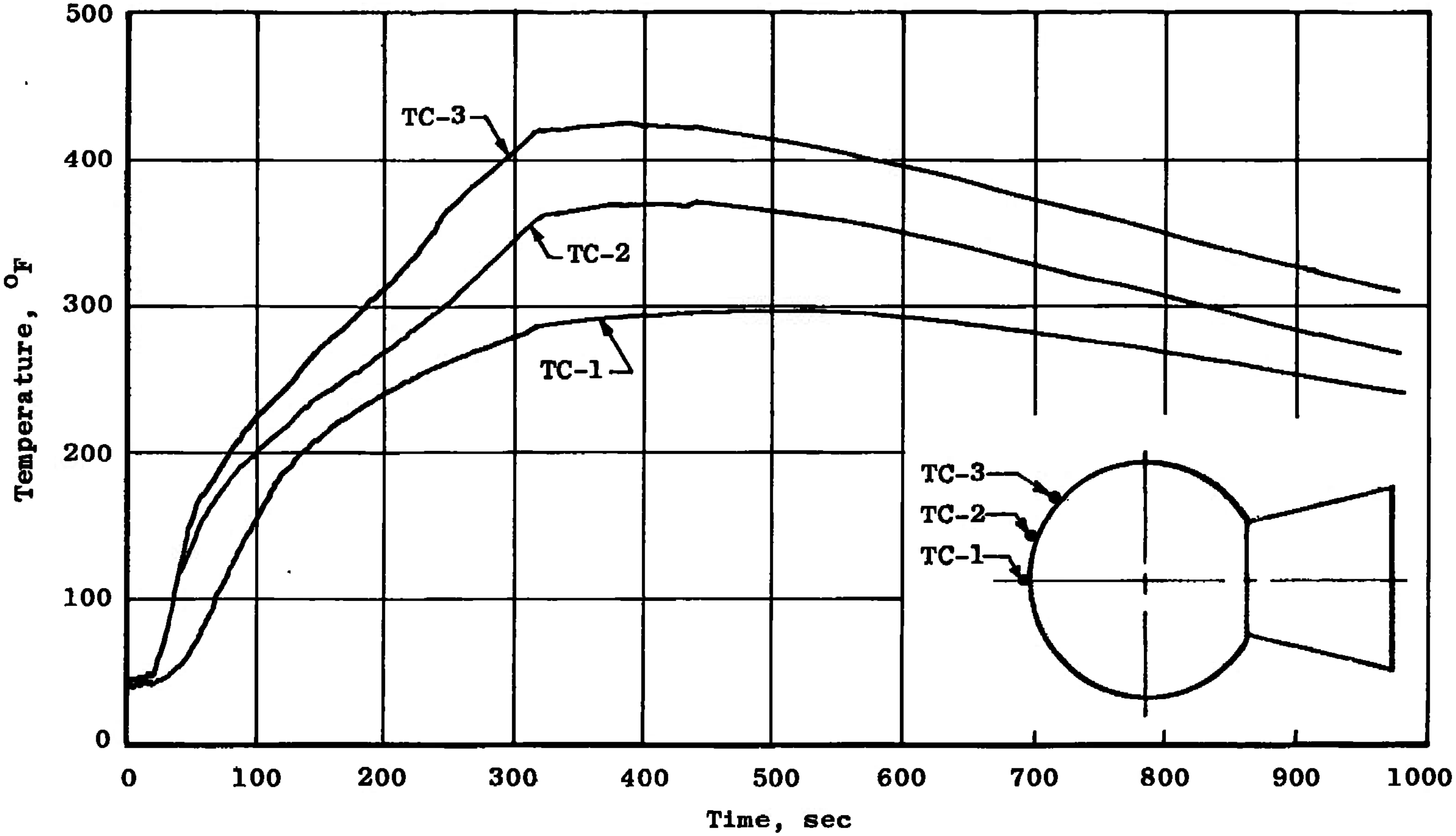


a. Exterior

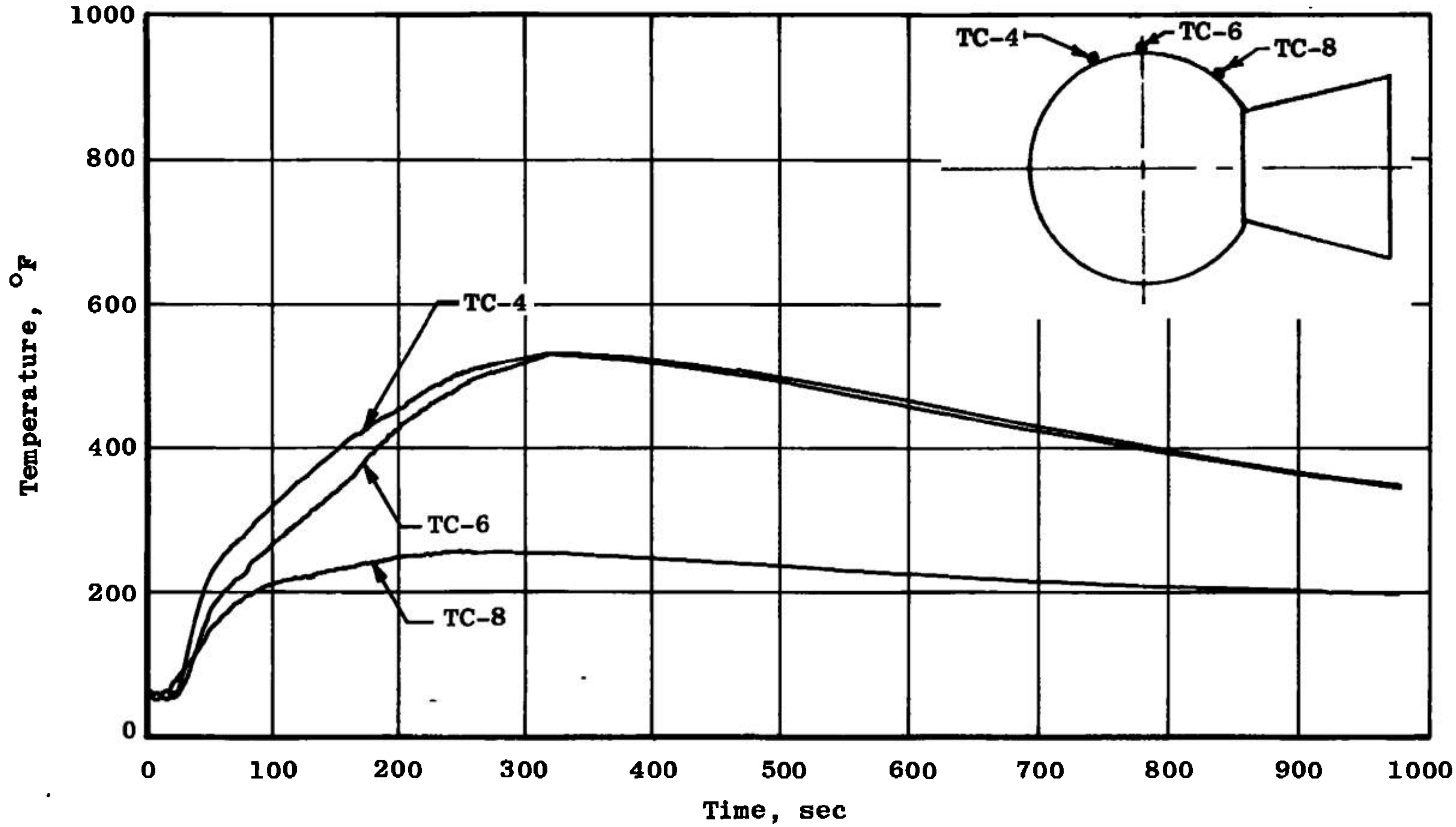
Fig. 6 Photograph Showing Postfire Condition of the TE-M-479 Rocket Motor (S/N PV32-284-3)



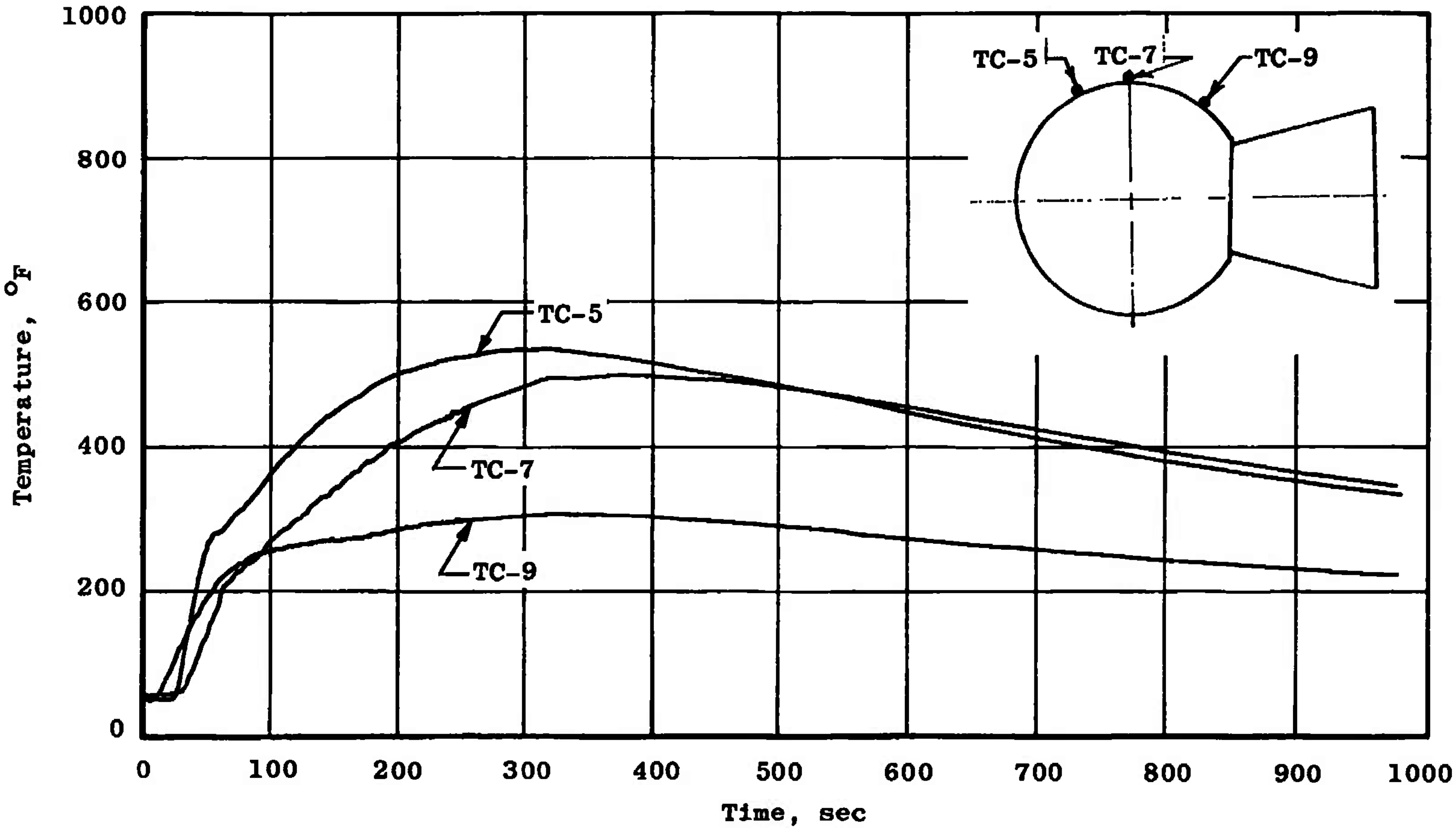
b. Interior
Fig. 6 Concluded



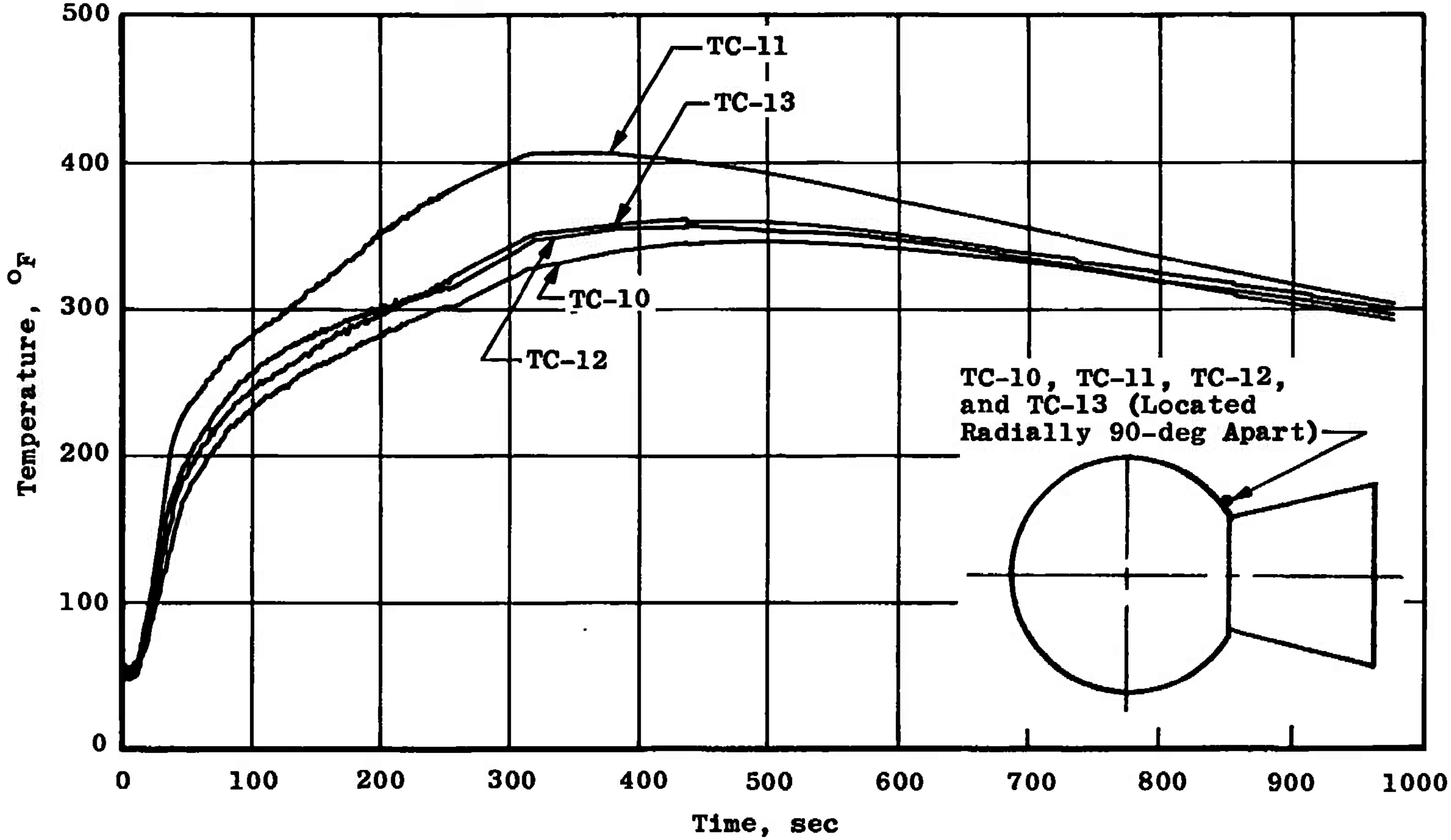
a. Motor Case (TC-1, TC-2, and TC-3)
Fig. 7 Temperature Variation with Time



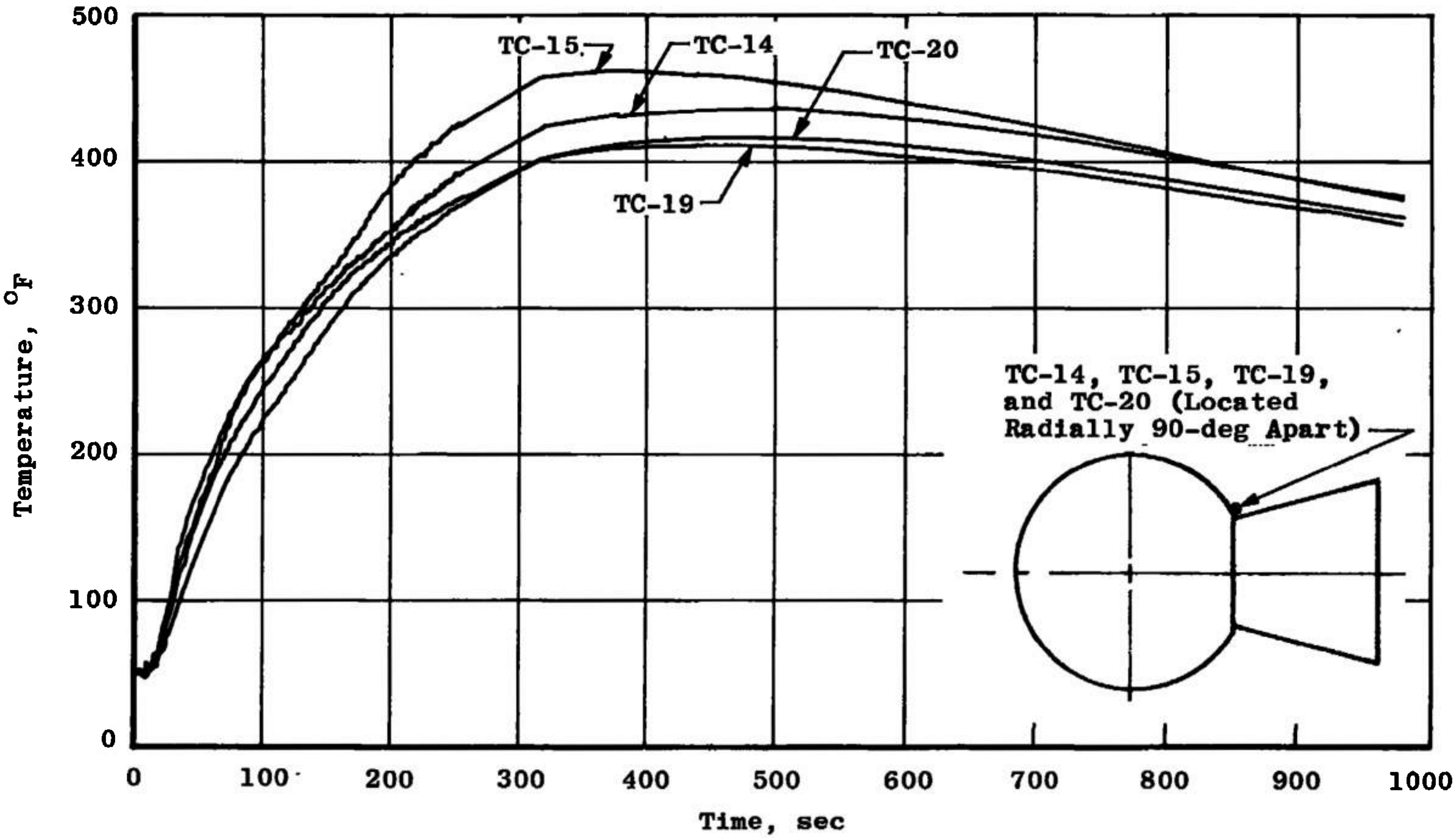
b. Motor Case (TC-4, TC-6, and TC-8)
Fig. 7 Continued



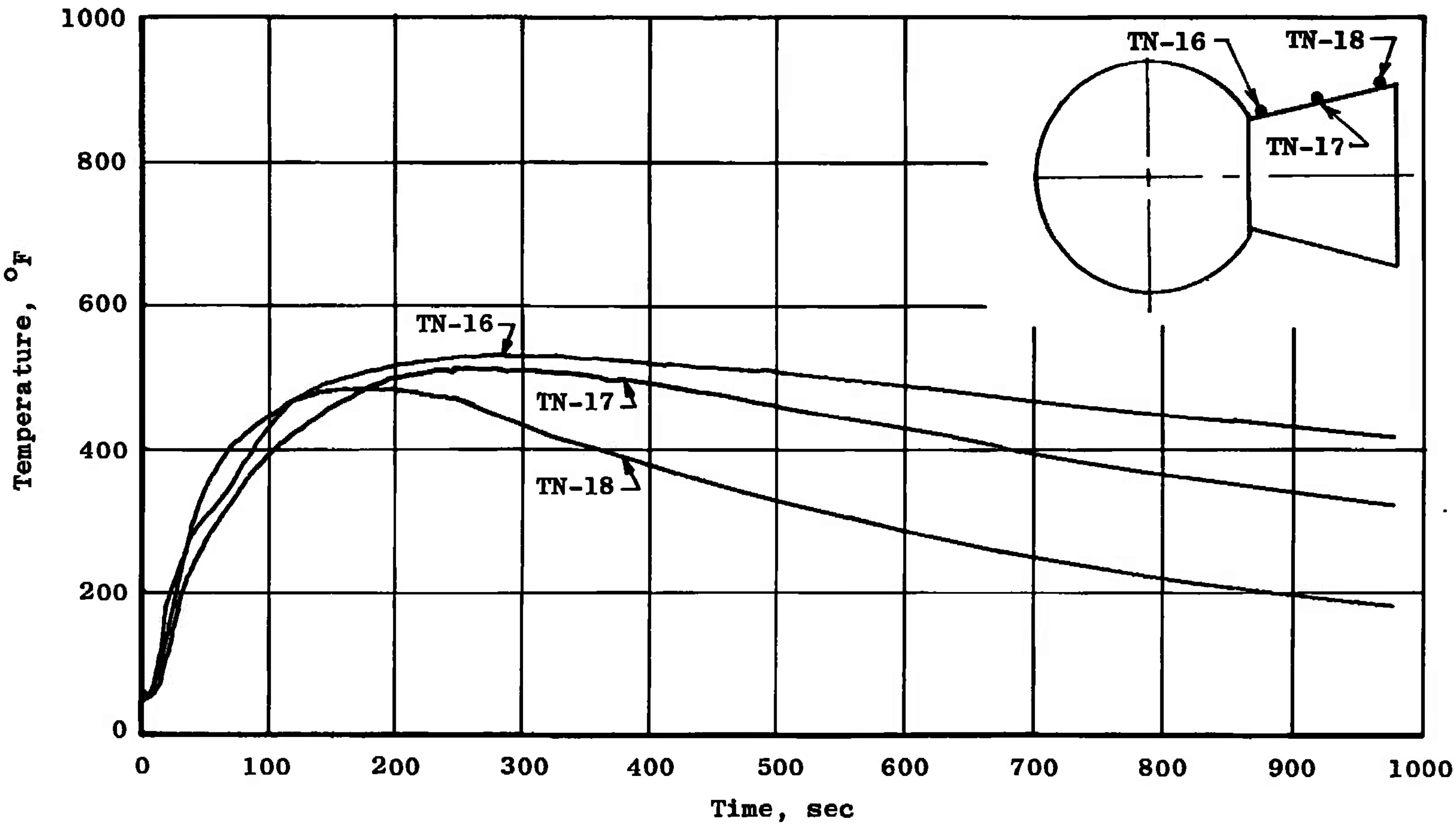
c. Motor Case (TC-5, TC-7, and TC-9)
Fig. 7 Continued



d. Motor Case (TC-10, TC-11, TC-12, and TC-13)
Fig. 7 Continued



e. Motor Case (TC-14, TC-15, TC-19, and TC-20)
Fig. 7 Continued



f. Nozzle (TN-16, TN-17, and TN-18)
Fig. 7 Concluded

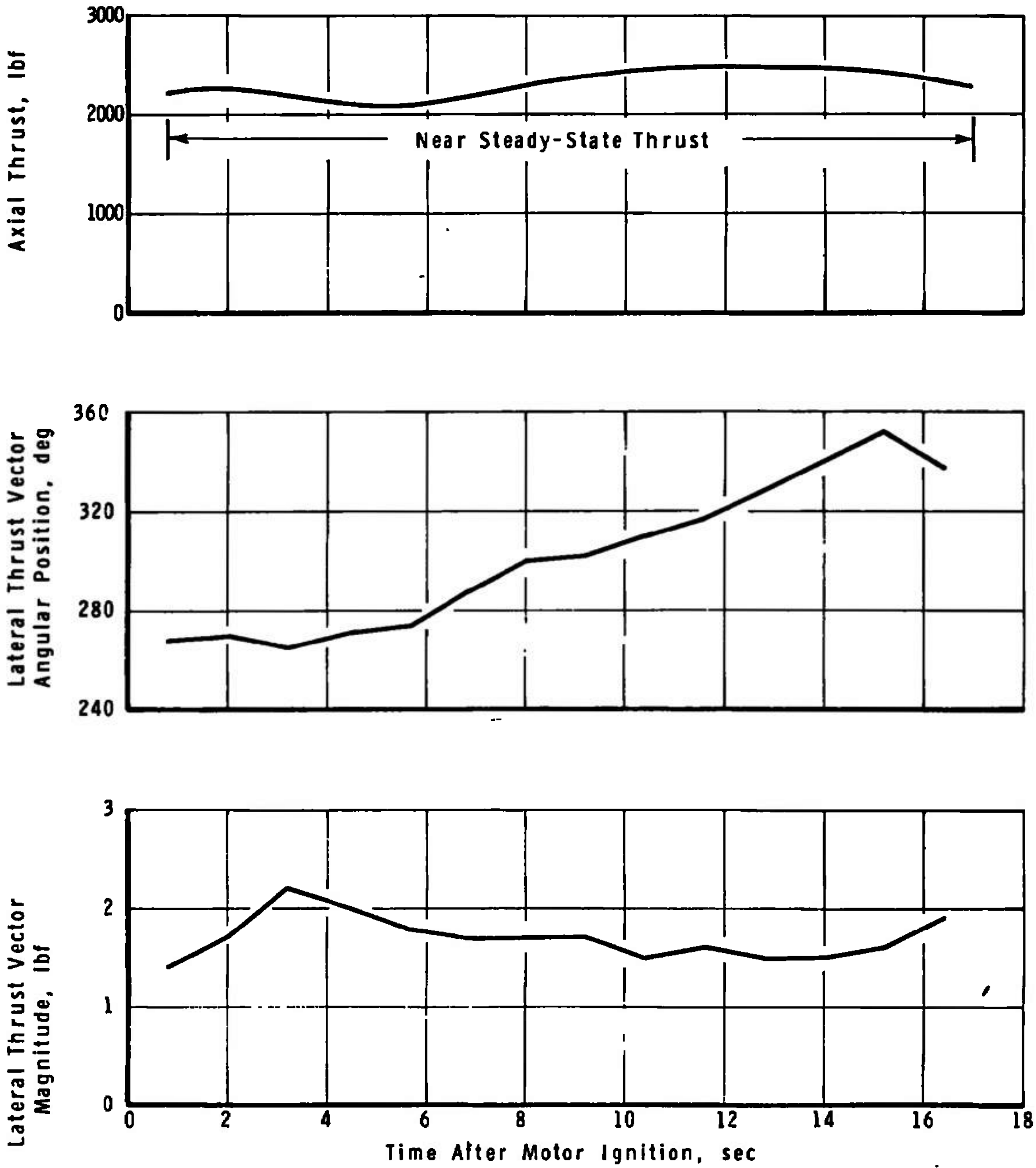
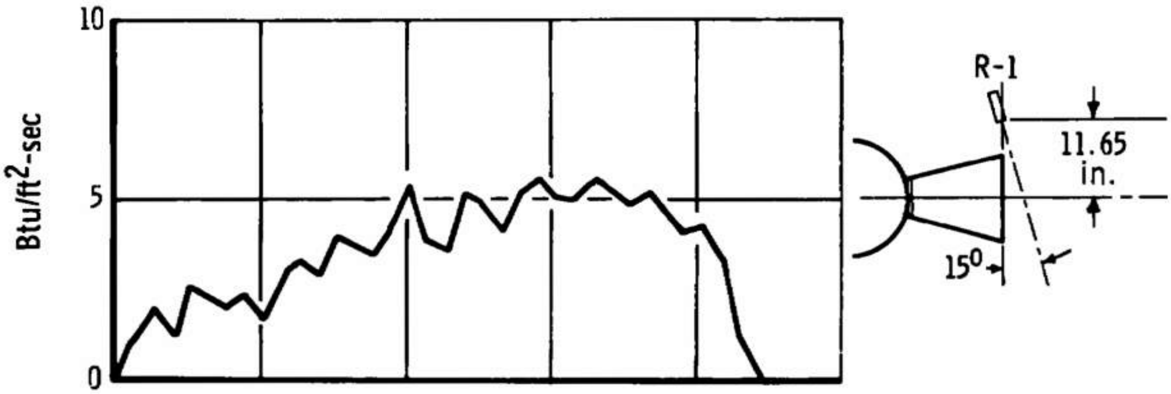
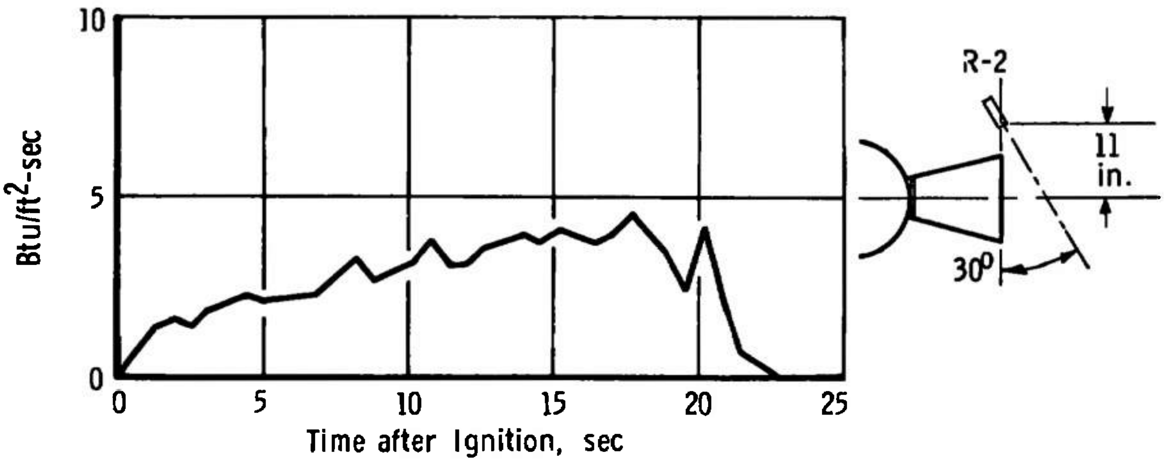


Fig. 8 Variation of Lateral Thrust Vector during Firing

a. Calorimeter, C-1 (View Angle = 140 deg)

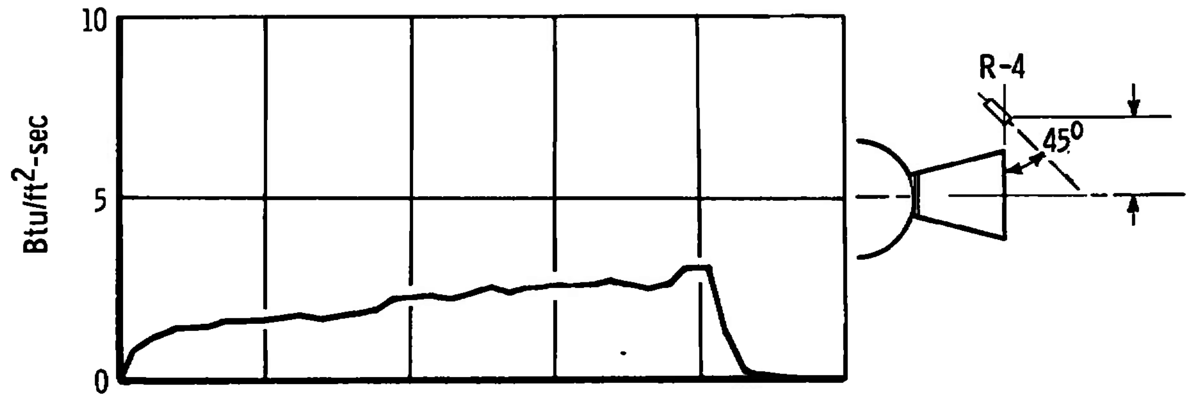


b. Radiometer, R-1 (View Angle = 30 deg)

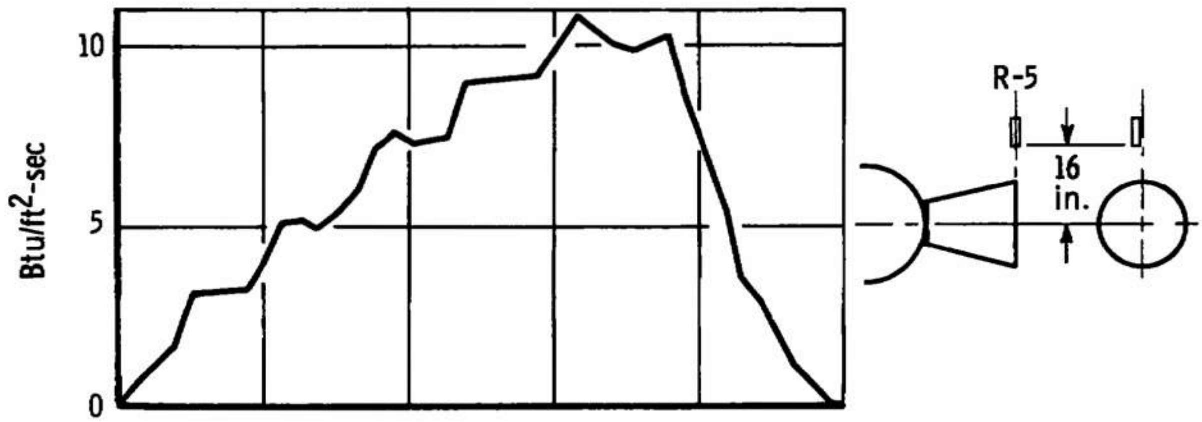


c. Radiometer, R-2 (View Angle = 60 deg)

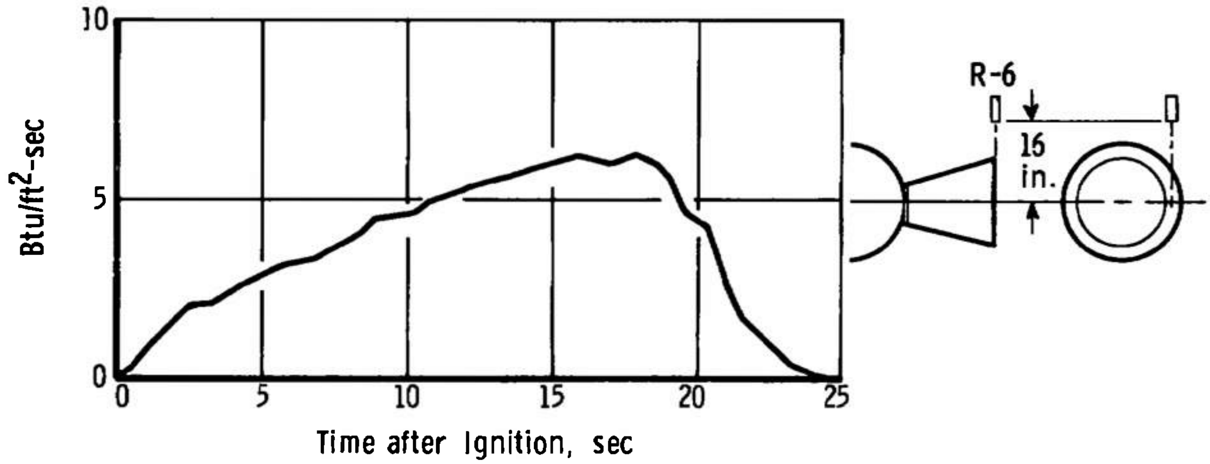
Fig. 9 Exhaust Plume Radiation Variations with Time



d. Radiometer, R-4 (View Angle = 90 deg)



e. Radiometer, R-5 (View Angle = 3 deg)



f. Radiometer, R-6 (View Angle = 3 deg)

Fig. 9 Concluded

TABLE I
INSTRUMENTATION SUMMARY AND MEASUREMENT UNCERTAINTY

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT*								Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Precision Index (S)			Bias (B)		Uncertainty $\pm(B + t_{95}S)$		Range			
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement				
Chamber Pressure, psia	±0.15	---	99	±0.18	---	±0.48	---	700 to 900 psia	Bonded Strain Gage-Type Pressure Transducers	Voltage-to-Frequency Converter onto Magnetic Tape	Resistance Shunt Based on the Standards Laboratory Determination of Transducer Applied Pressure versus Resistance Shunt Equivalent Pressure Relationship
Chamber Pressure Integral, psia-sec	±0.14	---	31	±0.18	---	±0.48	---				
Low-Range Chamber Pressure, psia	±(0.1% + 0.002 psi)		31	±(0.04% + 0.008 psi)		±(0.24% + 0.012 psi)		2.5 to 4.0 psia			
	±(0.1% + 0.002 psi)			±0.24	---	±(0.44% + 0.004 psi)		4.0 to 40 psia			
Test Cell Pressure, psia	±0.20	---	198	±1.7	---	±2.1	---	0.6 to 0.12 psia	Unbonded Strain-Gage-Type Pressure Transducers		
Test Cell Pressure Integral, psia-sec	±0.20	---	31	±1.7	---	±2.1	---				
Axial Force, lbf	±0.12	---	198	±0.08	---	±0.32	---	2000 to 3000 lbf	Bonded Strain-Gage-Type Pressure Transducers		In-Place Application of Deadweights Calibrated in the Standards Laboratory
Total Impulse, lbf sec	±0.11	---	31	±0.08	---	±0.30	---				
Lateral Thrust Vector Magnitude, lbf	---	±0.22 lbf	31	---	±0.56 lbf	---	±1.00 lbf	1.0 to 2.5 lbf		Sequential Sampling, Millivolt-to-Digital Converter, and Magnetic Tape Storage Data Acquisition System	In-Place Application of Multiple Force Levels Measured with Force Transducers Calibrated in the Standards Laboratory
Motor Temperature, °F	---	±0.25°F	95	---	±2.2°F	---	±2.7°F	40 to 530°F	Chromel-Alumel Temperature Transducers		Millivolt Substitution Based on the NBS Temperature versus Millivolt Tables
Weight, lbm	---	±0.015 lbm	31	---	±0.015 lbm	---	±0.045 lbm	180 to 350 lbm	Beam Balance Scales	Visual Readout	In-Place Application of Deadweights Calibrated in the Standards Laboratory
Time Interval, msec	---	±0.25 msec	31	---	±0.01 msec	---	±0.5 msec	---	Time Pulse Generator	Photographically Recording Galvanometer Oscillograph	Time Pulse Generator Calibrated in the Standards Laboratory

*Reference: CPIA No. 180. "ICRPG Handbook for Estimating the Uncertainty in Measurements made with Liquid Propellant Rocket Engine Systems." April 30, 1969.

TABLE II
SUMMARY OF TE-M-479 MOTOR PERFORMANCE

Test Number	RA293-01
Motor S/N	PV32-284-3
Test Date	5-2-73
Motor Case Temperature at Ignition, °F	50
Ignition Lag time (t_ℓ)*, sec	0.013
Action Time (t_a)**, sec	19.90
Full-Duration Burn Time (t_{fb})***, sec	21.70
Simulated Altitude at Ignition, ft	119,000
Average Simulated Altitude during t_a, ft	110,000
Measured Total Impulse (Based on t_a), lbf-sec	43,878
Number of Channels Averaged	3
Maximum Deviation of Individual Channel from Average, percent	0.01
Measured Total Impulse (Based on t_{fb}), lbf-sec	44,009
Number of Channels Averaged	3
Maximum Deviation of Individual Channel from Average, percent	0.01
Chamber Pressure Integral (Averaged Two Channels, Based on t_{fb}), psia-sec	****
Cell Pressure Integral (Average of Four Channels, Based on t_{fb}), psia-sec	2.4212
Maximum Deviation of Individual Channel from Average, percent	0.43
Vacuum Total Impulse, lbf-sec	
Based on t_a	44,064
Based on t_{fb}	44,225
Vacuum Specific Impulse (Based on t_a), lbf-sec/lbm	
Based on the Manufacturer's Stated Propellant Weight	287.42
Based on AEDC Measured Expended Mass	281.96
Vacuum Specific Impulse (Based on t_{fb}), lbf-sec/lbm	
Based on the Manufacturer's Stated Propellant Weight	288.47
Based on AEDC Measured Expended Mass	282.99

*Time Interval from zero time to time of increase in chamber pressure

**Time interval between 10 percent of maximum thrust during ignition and when thrust has fallen to 10 percent during tailoff.

***Time interval from first increase in thrust at ignition until thrust has returned to the prefire level at tailoff.

****Chamber Pressure Tap partially plugged during firing.

TABLE III
SUMMARY OF TE-M-479 MOTOR PHYSICAL DIMENSIONS

Test Number	RA293-01
Motor S/N	PV32-284-3
Test Date	5-2-73
AEDC Prefire Motor Weight*, lbm	341.03
AEDC Postfire Motor Weight*, lbm	184.75
AEDC Expended Mass, lbm	156.28
Manufacturer's Stated Propellant Weight, lbm	153.31
Nozzle Throat Area, in.^{2}	
Prefire**	1.481
Postfire	1.736
Percent Change from Prefire Measurement	17.2
Nozzle Exit Area, in.^{2}	
Prefire	90.030
Postfire	88.635
Percent Change from Prefire Measurement	-1.5

*Includes Igniter Weight and AEDC Firing Harness

**Supplied by Motor Manufacturer

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13. ABSTRACT

One Thiokol Chemical Corporation TE-M-479 solid-propellant rocket motor, (S/N PV32-284-3) modified for use in the Radio Astronomy Explorer -B (RAE-B) spacecraft, was tested at an average pressure altitude of 110,000 ft while spinning about its axial centerline at 50 rpm. The primary objectives of this program were to determine the altitude ballistic performance of the motor when preconditioned at 40 ± 5°F, determine motor temperature-time history, evaluate component structural integrity, and determine the nonaxial (lateral) force produced by the motor while spinning about its axial centerline at 50 rpm. This test was conducted as a part of the design assurance program for the modified TE-M-489 motor. Motor ballistic performance, temperature-time history during and after motor operation, structural integrity evaluation, and lateral force force data are presented and discussed.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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solid propellants						
ignition characteristics						
ballistic performance						

AFSC
Arnold AFS Tenn